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The nature of ionized gas in early-type galaxies

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Abstract.

We present a study of the ionized gas in a sample of 65 nearby early-type galaxies, for which we have acquired optical intermediate-resolution spectra. Emission lines are detected in $\sim 89\%$ of the sample. The incidence of emission appears independent from the E or S0 morphological classes. According to classical diagnostic diagrams, the majority of the galaxies are LINERs. However, the galaxies tend to move toward the “Composites” region (at lower $[\text{NII}]\lambda 6584/\text{H}\alpha$ values) as the emission lines are measured at larger galacto-centric distances. This suggests that different ionization mechanisms may be at work in LINERs.

1. Introduction

Early-type galaxies (ETGs) have long been considered to be inert stellar systems, essentially devoid of gas and dust. However, this view has radically changed since a number of imaging and spectroscopy studies from both the ground and space have revealed the presence of a multiphase interstellar medium (ISM): a hot ($T \sim 10^6 - 10^7$ K), X-ray emitting halo (e.g., Fabbiano et al. 1992); a warm ($T \sim 10^4$ K) component (often referred to as “ionized gas”) (e.g., Phillips et al. 1986); and even cooler components detected in the MIR (Bressan et al. 2006) and in HI and CO (e.g., Sadler et al. 2002). Ionized gas is detected in 40-80 % of early-type galaxies via its optical emission lines (e.g., Sarzi et al. 2006; Yan et al. 2006; Serra et al. 2008).

Despite the number of studies, several issues remain still open. The first question is the origin of the ISM in ETGs. Evidence for external acquisition comes from narrow-band imaging studies, often showing gas/star misalignment (e.g., Buson et al. 1993), and from kinematical studies, often showing gas/star angular momentum decoupling (e.g., Caon et al. 2000).

The second still open issue concerns the ionizing source of the warm gas. Optical spectroscopic studies show that ETGs are typically classified as Low-Ionization Emission-line Regions (LINERs) according to their emission line ratios (e.g., Phillips et al. 1986). However, there is still strong debate about the ionization mechanism in LINERs. Actually, the most viable excitation mechanisms are: low accretion-rate AGN (e.g., Kewley et al. 2006), photoionization by old post-asymptotic giant branch (post-AGB) stars (e.g., Binette et al. 1994), fast shocks (e.g., Dopita & Sutherland 1995).

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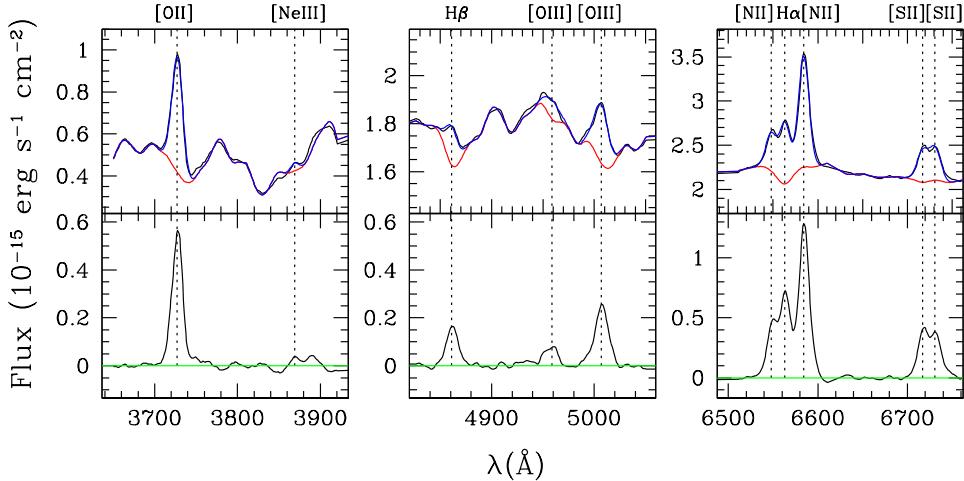


Figure 1. Spectrum of IC 1459 at $r < r_e/16$. Top panel: galaxy spectrum, normalized SSP model, and total fit obtained by adding emission lines to the underlying stellar continuum. Bottom panel: residual spectrum.

2. The Sample

With the aim of understanding the nature of ionized gas in ETGs, we acquired intermediate-resolution ($\text{FWHM} \approx 7.6 \text{ \AA}$ at 5550 \AA) optical spectra ($3700 - 7250 \text{ \AA}$) for a sample of 65 nearby E/S0 galaxies. For a detailed description of the sample we refer to Rampazzo et al. (2005) (Paper I) and Annibali et al. (2006) (Paper II). For the derivation of ages, metallicities, and $[\alpha/\text{Fe}]$ ratios, we refer to Annibali et al. (2007) (Paper III). Here we recall that the sample was selected from a compilation of galaxies showing ISM traces in at least one of the following bands: IRAS $100 \mu\text{m}$, X-ray, radio, HI and CO (Roberts et al. 1991). Because of the selection criteria, the sample is biased toward the presence of emission lines. The galaxies are mainly located in low density environments. In the present study, we will use the spectra extracted in 4 annuli of increasing galacto-centric distance ($0 \leq r \leq r_e/16$, $r_e/16 \leq r \leq r_e/8$, $r_e/8 \leq r \leq r_e/4$, and $r_e/4 \leq r \leq r_e/2$).

3. Emission lines

The emission line fluxes were measured on residual spectra obtained by subtracting the stellar population contribution to the observed galaxy spectra. To this purpose, we used new SSPs (Bressan, unpublished; Chavez et al. (2009)). The SSPs were computed from the isochrones of Bertelli et al. (1994), with the revision of Bressan et al. (1998) including a new AGB mass-loss treatment. In the optical domain, the SSPs are based on the MILES spectral library (Sánchez-Blázquez et al. 2006). The galaxy continua were fitted with the new SSPs, smoothed to match the instrumental resolution and the galaxy velocity dispersion, through a χ^2 criterion. In the fit, we considered selected spectral regions chosen to include both features particularly sensitive to age (the relative strength of the Ca II H + K lines, the 4000 \AA break, the H γ and H δ lines), and features more sensitive

to metallicity (the Fe lines at λ 4383, 4531, 5270, 5335, and the Mg absorption features around λ 5175). The residual spectrum around each line was derived by normalizing the SSP in two continuum bands adjacent to the line of interest. The line fluxes were determined by fitting the residual spectrum with Gaussian curves of variable width and intensity. As an example, we show the stellar continuum subtraction and the line fit for IC 1459 in Fig. 1. The emission lines were corrected for extinction through the observed $F(\text{H}\alpha)/F(\text{H}\beta)$ flux ratio, assuming an intrinsic value of ≈ 3.1 valid for AGN-like objects (Osterbrock 1989). Some galaxies in the sample present very large reddening, up to $E(B - V) \sim 1.5$ or even more. Since the observed continuum is incompatible with such large values, the dust must be patchy.

Emission lines are detected in 58 out of 65 galaxies ($\sim 89\%$ of the sample). The incidence of emission appears independent from the E and S0 morphological classes. The nebular emission is stronger in the galaxy center, and decreases moving toward the more external annuli.

4. Diagnostic Diagrams

Galaxies were classified through the standard $[\text{OIII}]\lambda 5007/\text{H}\beta$ versus $[\text{NII}]\lambda 6583/\text{H}\alpha$ diagnostic diagram, first proposed by Baldwin et al. (1981) (hereafter BPT). The BPT diagram for our galaxy sample, in the 4 annuli, is shown in Fig. 2. The majority of galaxies are classified as LINERs. Only IC 5063 is classified as a *bona fide* Seyfert galaxy. A few galaxies, namely NGC 3489, NGC 3818, NGC 3136, NGC 6776, NGC 7007, NGC 777, and NGC 6958, fall in the Seyfert region, but are consistent with a LINER classification within the errors. Some galaxies (NGC 3258, NGC 4552, NGC 5193, NGC 5328, NGC 6721, NGC 6876, IC 2006) fall in the “Composites” region (see Fig. 2), and possibly contain a combined contribution from both star formation and AGN. We notice that, from the center outwards, the bulk of the galaxies move left-down in the BPT diagram. An increasing number of galaxies pass from LINERs to “Composite” objects as the emission lines are measured at larger galacto-centric distances. This suggests that different ionization mechanisms may be at work in LINERs.

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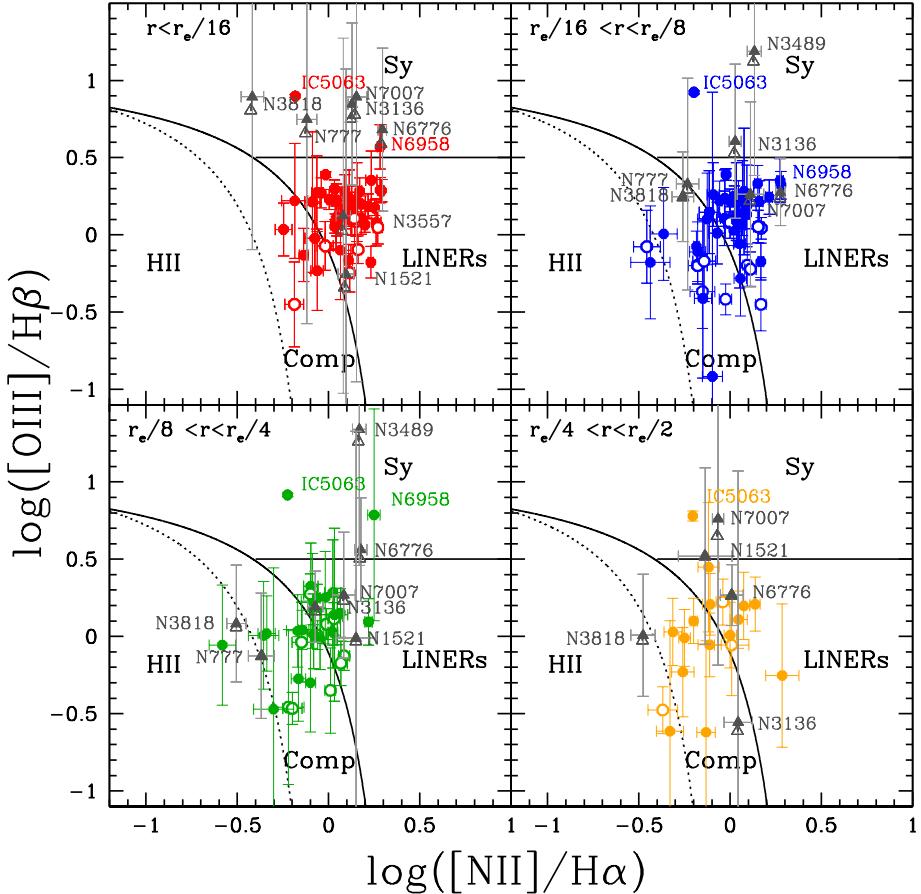


Figure 2. Extinction corrected diagnostic diagram for our sample in 4 annuli of increasing galacto-centric distance. Empty circles denote the galaxies with problematic reddening derivation. Triangles are for galaxies with $E(B - V) > 1.5$. Full and empty triangles indicate observed and reddening-corrected line ratios, respectively. The solid curve is the “maximum starburst line” of Kewley et al. (2001), while the dashed line indicates the empirical division between pure star-forming galaxies and “Composite” objects. The horizontal line at 0.5 separates Seyfert and LINER galaxies.

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